EFFECT OF YARN TYPE ON KNITTED FABRIC THERMOPHYSIOLOGICAL COMFORT
D. Kopitar*, Z. Pavlovic, Z. Skenderi and Z. Vrljicak

Abstract
The knitted fabric thermophysiological comfort is influenced by fabric characteristics and structure, including yarn spinning and finishing process. The research on viscose double jersey knitted fabrics knitted from ring, rotor and SIRO spun yarns counts of 20 tex were carried out. Beside the knitted fabric structure parameters analysis, thermal and water vapour resistance using the Sweating Guarded Hot Plate according to standard ISO 11092:2014 were determinate. The yarns made by different spinning processes have an impact on the knitted fabric structural parameters, thus on thermal and water vapour resistance. The greatest reduce of the thermal resistance were obtained after finishing process of knitted fabric made by SIRO yarn. Greatest difference in the water vapour resistance is between knitted fabrics made of ring and rotor yarns.

Key Terms
Knitted fabric, conventional and unconventional yarns, SGHP, thermal and water vapour resistance

1. Introduction
To provide thermo-physiological comfort of the knitted fabrics worn next to the skin, knitted fabric must have ability to absorb heat, vapour and liquid perspiration from skin and then transfer it outside of the fabric [1]. The knitted fabric thermal and moisture properties are significantly influenced by fabric characteristics and structure, i.e. influenced by the type of fibre, yarn spinning method, count, twist and hairiness, fabric thickness cover factor, porosity and applied finishing [2-5]. Spinners are always trying to produce better quality yarn with low cost. The rotor spinning is the cheapest spinning method considering ring and Siro spinning technologies. Limitation of rotor yarn is less strength of the produced yarn. Siro spinning is the similar type of ring spinning process in which two roving’s are fed to drafting at the same time and twisted together as a double yarn. As a result of Siro process, more even than single yarn at the same count and less hairy yarns are produced. The presented research is focused on investigation of the relationship between viscose knitted fabrics suitable for layer worn next to the skin, made of different yarn spinning method (ring spun, rotor and SIRO yarns), and thermo-physiological properties. Viscose ring spun, rotor and SIRO yarns have been used for producing single jersey plain knitted fabric in order to analyse yarn type effect on knitted fabric thermo-physiological comfort.

2. Experimental
2.1. Materials
For knitting the samples, a circular double bed knitting machine was used (Figure 1). This type of knitting machine is generally used to knit plain double knit jersey fabrics intended to manufacture underwear. Its gauge is E17 with 432 x 2 needles and it is recommended to knit single cotton yarns from 12 to 36 tex or ply yarns from 10 tex x 2 to 17 tex x 2. The machine knits with 8 knitting systems so it is necessary to prepare 8 packages for each yarn group. Coni positive feeders regulating the tensile force of the yarn fed to the knitting system, which amounted to 3±1 cN were used to feed the yarn to the machine. The twenty meters of each
sample were made. The fabric take-down was performed by two pairs of rollers that are located 70 cm away from the knitting zone. The fabric was plaited down on the tray below the take down rollers, i.e. it was not wound onto a fabric roll. The research work was carried out on three viscose double jersey knitted fabrics, knitted from ring, rotor and SIRO spun yarns.

2.1. Methods

In the knitted fabric structure parameters analysis, basic parameters such as horizontal \((D_h)\) and vertical fabric density \((D_v)\), fabric thickness \((t)\) and mass per unit area \((m)\) are significant and therefore tested. Based on the fabric thickness and mass per unit area, porosity and fabric thickness cover factor were calculated.

From the number of needles in the cylinder and the width of the knitted fabric, horizontal fabric density \((D_h, \text{ number of loops in course direction})\) can be determined using this equation:

\[
D_h = \frac{N_i}{S_p}
\]

Where: \(D_h\) is the horizontal fabric density in cm\(^{-1}\), \(N_i\) is the number of needles, \(S_p\) is the width of the fabric in cm.

Vertical fabric density \((D_v, \text{ number of loops in wale direction})\) was measured on the sample, counting the loops in one course at a certain length. Thickness \((t)\) was measured using the precision Thickness Gauging testing device model 2000-U, from HESS MBV GmbH, according to DIN EN ISO 5084, and this standard recommends using a pressure of 1 kPa by a stamp with diameter of 50.5 mm.

Fabric grammage or mass per unit area \((m)\) is the most important technological and economical parameter of the knitted fabric structure, and can be determined by weighing the mass of the fabric and calculating its surface area with this equation:

\[
m = \frac{m_u}{P_u}
\]

Where: \(m\) is mass per unit area in gm\(^{-2}\), \(m_u\) is the weight of the knitted sample in g, \(P_u\) is the surface area in m\(^2\).

Thickness cover factor \((T_{cf})\) is calculated with the ratio of mass per unit area and fabric thickness:

\[
T_{cf} = \frac{m}{1000 \cdot t}
\]
Where: \( T_{cf} \) is thickness cover factor in gm\(^{-3}\), \( m \) is mass per unit area in gm\(^{-2}\), and \( t \) is fabric thickness in mm.

The porosity of the knitted fabric (\( P \)) is analysed as the ratio of the mass of the substance that makes the fabrics and the yarn volume of the knitwear. For the porosity of knitted fabric, the main data is the average density of fibers (\( \gamma \)) that builds the knitted structure, Figure 2. Porosity was calculated according to the following equation [6]:

\[
P = \frac{\gamma - T_{cf}}{\gamma} \cdot 100
\]

Where: \( P \) is porosity, \%, \( \gamma \) is the density of the viscose fiber, 1.47647 g cm\(^{-3}\), \( T_{cf} \) is the thickness cover factor, gm\(^{-3}\).

Using Dino-Lite with magnification of 70x and 190x images of knitted fabric structures were taken (Figure 2.).

![Magnification 70 x](image1)

![Magnification 190 x](image2)

![CV ring\(_{raw}\)](image3)

![CV rotor\(_{raw}\)](image4)
Thermo-physiological properties, were determinate by measuring thermal and water-vapour resistance under steady-state conditions using the Sweating Guarded Hot Plate according to standard ISO 11092:2014. The Sweating Guarded Hot Plate device is used to measure the thermal resistance ($R_{ct}$) and water vapour resistance ($R_{et}$) of knitted fabrics. The hot plate is a porous plate with distinct drilled holes pattern providing simulation of human skin. So called “skin model” simulates the heat and mass transfer processes that occur next to the human skin. The SGHP model consist of temperature controller, water supply unit and measuring unit (Figure 3) [7]. The SGHP is placed in metal chamber in order to provide controlled standard environment. Standard environment for thermal resistance testing of air temperature is $20 \pm 0.1 \degree C$ and relative humidity of $65 \pm 3\%$, i.e. for testing water vapour resistance air temperature is $35 \pm 0.1 \degree C$ and relative humidity is $40 \pm 3\%$. The test area of 3 mm thick square porous metal plate is surround by the guard heaters, which prevent lateral heat leakage, and guard heater beneath plate to prevent downward heat loss. The heaters arrangement drives heat or moisture to transfer only along the knitted fabric sample. The thermocouple sensor placed directly below the plate surface measures the temperature of the plate.

To test thermal resistance, the knitted fabric sample was place on the hot plate dimensions 250 x 205 mm in controlled standard environment (air temperature of $20 \pm 0.1 \degree C$, relative humidity
of 65 ± 3%). The thermal resistance of the fabric is calculated according to the following equation [8, 9]:

\[ R_{ct} = \frac{(T_m - T_a) A}{H - \Delta H_c} - R_{ct0} \]  

(1)

Where: \( R_{ct} \) is the thermal resistance in m\(^2\) °C W\(^{-1}\), \( T_m \) is temperature of measuring unit in °C, \( T_a \) is the air temperature during testing in °C, \( A \) is the area of the measuring unit in m\(^2\), \( H \) is the heating power supplied to the measuring unit in W, \( \Delta H_c \) is the correction term for heating power for the measurement of thermal resistance and \( R_{ct0} \) is the apparatus constant for the measurement of thermal resistance in m\(^2\) °C W\(^{-1}\).

Water vapour resistance is defined as the water vapour pressure difference between two faces of a material divided by the resultant evaporative heat flux per unit area. To test water vapour resistance the knitted fabric samples were placed above liquid water impermeable membrane, which allow only water vapour to pass. To create the water vapour, the water from water tank (Figure 3) is passing through hot plate guard heater section, get preheated and delivered to the hot plate surface at constant rate of evaporation. The water-vapour resistance of the fabric is calculated according to the following equation [4, 5]:

\[ R_{et} = \frac{(p_m - p_a) A}{H - \Delta H_e} - R_{et,0} \]  

(1)

Where: \( R_{et} \) is the water-vapour resistance in m\(^2\) Pa W\(^{-1}\), \( p_m \) is the saturation of water-vapour partial pressure in Pa at the surface of the measuring unit at temperature \( T_m \) in °C, \( p_a \) is the water-vapour partial pressure in Pa of the air in the test enclosure at \( T_a \) °C, \( A \) is the area of the measuring unit in m\(^2\), \( H \) is the heating power supplied to the measuring unit in W, \( \Delta H_e \) is the correction term for the heating power in W, and \( R_{et,0} \) is the bare plate evaporative resistance in m\(^2\) Pa W\(^{-1}\).

3. Results and Discussion

The results of the knitted fabric parameters, i.e. mass per unit area, knitted fabric thickness, horizontal and vertical knitted fabric density, calculated knitted fabric porosity and thickness cover factor are presented in Table 1. The results of thermal resistance are shown in Table 2, while the water vapour resistance are presented in Table 3. All tested yarns were spun with same fibre type and parameters (Lenzing viscose, length of 38 mm, fineness of 1.3 dtex) with nominal yarn count of 20 tex. All the samples were made on one machine and under the same conditions, i.e. without machine operation control. A change in all parameters of knitted fabric structure was reflected through fabric mass per unit area, which ranged from 131 g m\(^{-2}\) (knitted fabric made of rotor yarn) to 180 g m\(^{-2}\) (knitted fabric made of SIRO yarn) (Tab. 1.), respectively the minimum and maximum knitted fabric mass per unit area difference is up to 37%.

<table>
<thead>
<tr>
<th>Sample</th>
<th>( m,\ g\ m^{-2} )</th>
<th>( t,\ mm )</th>
<th>( D_v,\ cm^{-1} )</th>
<th>( D_h,\ cm^{-1} )</th>
<th>( P,\ % )</th>
<th>( T_{ef},\ g\ m^{-3} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV_ringraw</td>
<td>165</td>
<td>0.63</td>
<td>11.8</td>
<td>10.9</td>
<td>82.39</td>
<td>0.26</td>
</tr>
<tr>
<td>CV_rotorraw</td>
<td>131</td>
<td>0.59</td>
<td>12.0</td>
<td>8.6</td>
<td>85.09</td>
<td>0.22</td>
</tr>
<tr>
<td>CV_SIROraw</td>
<td>180</td>
<td>0.72</td>
<td>12.6</td>
<td>11.2</td>
<td>83.06</td>
<td>0.25</td>
</tr>
<tr>
<td>CV_SIROfinished</td>
<td>147</td>
<td>0.37</td>
<td>11.9</td>
<td>9.7</td>
<td>74.91</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Table 1. Basic knitted fabrics properties
where: \( m \) is the mass per unit area, g m\(^{-2}\); \( t \) is the thickness, mm; \( Dh \) is the horizontal fabric density, cm\(^{-1}\); \( Dv \) is the vertical fabric density, cm\(^{-1}\); \( P \) is the porosity, %; \( T_{cf} \) is thickness cover factor, g m\(^{-3}\).

Comparing the knitting fabric thickness, influence of finishing process is evident. The thickness of knitted fabric made of SIRO spun yarns after finishing decrease for 48.6%.

Comparing thickness of knitted fabric made of ring, rotor and SIRO spun yarns produced on same knitting machine with same raw material and yarn count, influence of structure is visible. The range of thickness is from 0.59 mm up to 0.72 mm, i.e. SIRO spun yarn have higher thickness for 18.1% related to the rotor yarn. Certainly, different mass per unit area and thickness of knitted fabrics made of different type of yarns influenced on the knitted fabric horizontal and vertical density, porosity and cover factor.

### Table 2. The knitted fabrics thermal resistance

<table>
<thead>
<tr>
<th>Sample</th>
<th>( R_{ct}, \text{ m}^2 \text{ °C W}^{-1} )</th>
<th>( M, \text{ m}^2 \text{ °C W}^{-1} )</th>
<th>SD, ( \text{ m}^2 \text{ °C W}^{-1} )</th>
<th>CV, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV_ring_raw</td>
<td>0.0230</td>
<td>0.0235</td>
<td>0.0194</td>
<td>0.0220</td>
</tr>
<tr>
<td>CV_rotor_raw</td>
<td>0.0144</td>
<td>0.0129</td>
<td>0.0109</td>
<td>0.0127</td>
</tr>
<tr>
<td>CV_SIRO_raw</td>
<td>0.0202</td>
<td>0.0200</td>
<td>0.0203</td>
<td>0.0202</td>
</tr>
<tr>
<td>CV_SIRO_finished</td>
<td>0.0177</td>
<td>0.0136</td>
<td>0.0166</td>
<td>0.0160</td>
</tr>
</tbody>
</table>

Where: \( S_1, S_2, S_3 \) is first, second and third tested knitted fabric sample, \( R_{ct} \), is the knitted fabric thermal resistance in \( \text{m}^2 \text{ °C W}^{-1} \), \( M \) is the knitted fabric thermal resistance mean value in \( \text{m}^2 \text{ °C W}^{-1} \), SD is the knitted fabric thermal resistance standard deviation in \( \text{m}^2 \text{ °C W}^{-1} \), CV is the knitted fabric thermal resistance coefficient of variation in %.

The thermal resistance of the knitted fabrics is in the range of 0.0127 \( \text{m}^2 \text{ °C W}^{-1} \) up to 0.0220 \( \text{m}^2 \text{ °C W}^{-1} \) (Table 2.). The smallest thermal resistance value have knitted fabric made of rotor yarn (0.0127 \( \text{m}^2 \text{ °C W}^{-1} \)), while the largest thermal resistance value have knitted fabric made of ring spun yarn (0.0220 \( \text{m}^2 \text{ °C W}^{-1} \)).

Comparing knitted fabric made of SIRO yarns, it is evident that finishing process reduce mass per unit area and thickness, thus porosity, which decrease thermal resistance of the knitted fabric (from 0.0202 \( \text{m}^2 \text{ °C W}^{-1} \) to 0.0160 \( \text{m}^2 \text{ °C W}^{-1} \)) (Figures 4-6). The knitted fabrics made of rotor yarns have smallest mass per unit area and thermal resistance (0.0127 \( \text{m}^2 \text{ °C W}^{-1} \)) although their thickness and porosity is greater than finished knitted fabrics made of SIRO yarns (Figures 4). The greater thermal resistance have knitted fabric made of ring spun yarns (0.0220 \( \text{m}^2 \text{ °C W}^{-1} \)).

![Figure 4. Influence of knitted fabrics mass per unit area on thermal resistance](image-url)
Considering basic knitted fabric parameters (mass per unit area, thickness and porosity) it can be concluded that specific structure of different yarn types, spun from viscose fibres of 20 tex yarn count influence on knitted fabric basic parameters thus on thermal resistance. Likewise, finishing after knitting process changes basic knitted fabric parameters and their thermal resistance.

The knitted fabrics water vapour resistance ranged from 3.03 to 4.03 m$^2$ Pa W$^{-1}$ and have very good physiological properties according to Hohenstein Institute from Germany (Table 3.). The fabric knit by rotor yarn show lowest water vapour resistance, while the greatest water vapour resistance have fabric made of ring spun yarn, i.e. as well as the results of the knitted fabrics thermal resistance. Comparing raw and finished knitted fabric knit from SIRO yarns, it is visible that finishing process reduced fabric water vapour resistance (from 3.94 m$^2$ Pa W$^{-1}$ to 3.25 m$^2$ Pa W$^{-1}$). The finishing process had an impact on the knitted fabric structural parameters. The untreated knitted fabric mass per unit area made by SIRO yarn (180 g m$^{-2}$) after finishing process was reduced to 147 g m$^{-2}$. After finishing process, thickness, porosity as well horizontal and vertical density of the knitted fabric made of SIRO yarns were significantly reduced.

Table 3. The knitted fabrics water vapour resistance

<table>
<thead>
<tr>
<th>Sample</th>
<th>$R_{et}$, m$^2$ Pa W$^{-1}$</th>
<th>$M$, m$^2$ Pa W$^{-1}$</th>
<th>SD, m$^2$ Pa W$^{-1}$</th>
<th>CV, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV_ring$_{raw}$</td>
<td>4.08</td>
<td>4.22</td>
<td>3.78</td>
<td>4.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.19</td>
<td>4.61</td>
</tr>
<tr>
<td>CV_rotor$_{raw}$</td>
<td>3.08</td>
<td>3.05</td>
<td>2.97</td>
<td>3.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.05</td>
<td>1.57</td>
</tr>
<tr>
<td>CV_SIRO$_{raw}$</td>
<td>3.89</td>
<td>3.95</td>
<td>3.99</td>
<td>3.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.05</td>
<td>1.16</td>
</tr>
<tr>
<td>CV_SIRO$_{finished}$</td>
<td>3.55</td>
<td>3.27</td>
<td>2.94</td>
<td>3.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.25</td>
<td>7.69</td>
</tr>
</tbody>
</table>

Where: $S_1$, $S_2$, $S_3$ is first, second and third tested knitted fabric sample, $R_{et}$, is the knitted fabric water vapour resistance in m$^2$ °C W$^{-1}$, $M$ is the knitted fabric water vapour resistance mean
value in m² °C W⁻¹, SD is the knitted fabric water vapour resistance standard deviation in m² °C W⁻¹, CV is the knitted fabric water vapour resistance coefficient of variation in %.

Differences of water vapour resistance between the knitting fabrics made of ring, SIRO and rotor yarns as well finished SIRO yarns counts of 20 tex are not significant considering that human body can't detected and feel such a small difference in comfort. Although, all tested knitted fabrics have good comfort (according to Hohenstein Institute from Germany), influence of different yarn types and finishing process on thermal and water vapour resistance is evident.

4. Conclusions

Based on the obtained results it is obvious that the yarns made by different spinning processes have an impact on the knitted fabric structural parameters, i.e. differences in knitted fabric mass per unit area, thickness and horizontal/vertical density were obtained. The greatest reduce of the thermal resistance were obtained after finishing process of knitted fabric made by SIRO yarn. Greatest difference in the water vapour resistance is between knitted fabrics made of ring and rotor yarns. Comparing raw and finished knitted fabric knit from SIRO yarns, it is visible that finishing process reduced knitted fabric water vapour resistance due to change of fabric parameters. Although, there are differences in water vapour resistance of the tested knitted fabric, their differences are not significant considering that human body can't detected and feel such a small difference in comfort parameters.

For broader conclusion, knitted fabrics produced from ring, rotor and SIRO yarns needs to be knit from different yarn counts and finished to investigate influence of different yarn types on thermal and water vapour resistance.

Acknowledgements

This work has been supported by the Croatian Science Foundation under the project (IP-2016-06-5278).

References

Author Information
Dragana Kopitar
University of Zagreb Faculty of Textile Technology
Prilaz baruna Filipovica 28a, 10 000 Zagreb, Croatia
+385 1 3712 574
dragana.kopitar@ttf.hr